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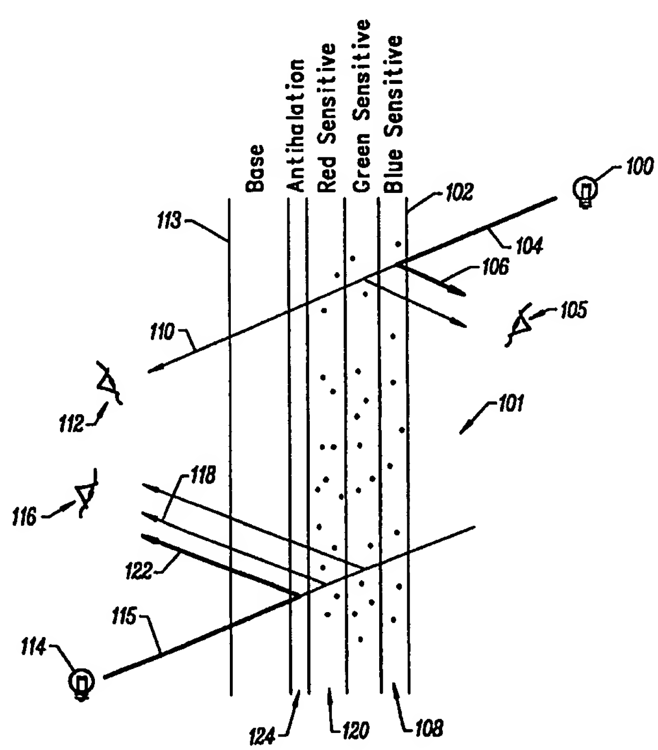
(54) Title: METHOD AND APPARATUS FOR REDUCING NOISE IN ELECTRONIC FILM DEVELOPMENT

## (57) Abstract

In electronic film development, a film (101) is scanned, using light, multiple times during development. The light is reflected from an emulsion containing milky undeveloped silver halide embedded with developing grains. The undeveloped halide layer has a finite depth over which photons from a light source scatter backward. This depth is within the range of the coherency length of infrared sources commonly used in electronic film development, causing coherency speckle noise in the scanned image. A prescan made after the emulsion swells, but before the silver grains develop, normalizes subsequent scans, pixel by pixel, to cancel coherency speckle and other defects.



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# METHOD AND APPARATUS FOR REDUCING NOISE IN ELECTRONIC FILM DEVELOPMENT

## RELATED APPLICATION

This application claims the benefit of U.S. Provisional Application No. 60/032,114, filed December 5, 1996.

## FIELD OF THE INVENTION

This invention generally relates to the electronic development of film and more particularly to a method and apparatus for reducing noise in electronic film development.

## BACKGROUND OF THE INVENTION

Electronic film development, also known as digital development, is a method of digitizing color film during the development process as disclosed in U.S. Patent No. 5,519,510 issued to the present inventor. Conversion of analog images into digital data, or scanning, has become widespread for a variety of uses, including storing, manipulating, transmitting, displaying or printing copies of the images.

In order to convert a photographic image into a digital image, the film image frame is transported through a film scanning station, and illuminated along each scan line with a linear light beam of uniform, diffuse illumination, typically produced by a light integrating cavity or integrator. The light transmitted through the illuminated scan line of the image frame is focused by a lens system on a CCD-array image detector which typically produces three primary color light intensity signals for each image pixel. These light intensity signals are then digitized and stored. Film scanners which enable the electronic development of film have a variety of forms today and the common aspects of film image frame digitizing, particularly line illumination and linear CCD array based digitizers, are described in greater detail in U.S. Patent No. 5,155,596.

In electronic film development, the developing film is scanned at a certain time interval(s) using infrared light so as not to fog the developing film, and also

to increase penetration of the light through any antihalation layers. Some of the incident light is reflected from an emulsion on the film which contains milky, undeveloped silver halide. The undeveloped halide emulsion has a finite depth over which the photons from the light source will scatter and reflect back toward a detector. This depth is within the range of the coherency length of infrared light sources commonly in use in electronic film development today. It is this finite reflective depth which causes noise in the scanned image due to coherency speckle. Noise in the scanned image results in capturing an image distorted by graininess.

Because of the longer wavelength of infrared light, both the wavelength and the dividing fractional bandwidth for a fixed bandwidth contributes to a longer coherency length than normally encountered in visible light. In addition, the width of the milky silver halide layers is very thin in electronic film development, reducing the coherency length necessary to produce interference speckle.

Furthermore, the image seen through the back side of the film is very faint, so any coherency speckle is amplified as the faint image is amplified and the image is distorted. This problem is apparent in scans of the film regardless of whether light is reflected from the top or bottom of the film, or is transmitted through the film. However, it is predominant in the rear reflection scan due to the increased light reflected by the antihalation layer. No prior art methods appear to address this significant problem. Generally, during film processing, the dry emulsion layer over the film substrate is subjected to an aqueous bath which causes the emulsion to expand. During electronic film processing, photons penetrating the emulsion strike particles suspended in the emulsion and reemerge to be registered by light sensors. As the emulsion expands, the distance between the photon reflecting particles varies proportionally. If the resulting difference between the photons' exit paths is a quarter wavelength difference, then a speckle point can change from black to white or from white to black. Thus, any attempt to remove the speckle effect by differencing images made while the emulsion is in a first expanded position and a subsequent second expanded position can actually make the speckle effect worse by

overlaying two different speckle patterns. For these reasons, coherency speckle is a significant problem in practicing electronic film development.

To view coherent speckle with the human eye, the path length traveled by the light can be no more than the coherency length of the light source. Beyond the coherency length, the speckle shimmers at the speed of light and appears to the viewer to be continuous. The characteristic grainy, or speckled, appearance of laser light, which is a coherent light source, is due to interference effects which result from coherence. Under laser light, everything in a room appears speckled, and the speckles appear to shimmer as the light, object, or viewer move.

Even under ordinary light, speckle is sometimes seen when there are very short path differences and very narrow light angles involved, as for example when viewing a white sheet of paper in direct sunlight. For noncoherent light, the coherency length is on the order of the wavelength divided by the percent bandwidth. Because this usually amounts only to a few wavelengths of light, coherency shimmer is not normally visible in real world viewing where noncoherent light is the norm.

It is, therefore, an object of this invention to provide a method of electronic film development which significantly reduces noise in capturing a developed or developing image.

It is another object of this invention to provide a method of electronic film development which significantly reduces or entirely eliminates coherent speckle in a developed image.

It is yet another object of the present invention to eliminate noise caused by coherent speckle during electronic film development which is altered by emulsion expansion.

To achieve these and other objects which will become readily apparent upon reading the attached disclosure and appended claims, an improved method of electronic film development which significantly reduces the amount of coherent speckle noise in an image is provided. Additional objects, advantages, and novel features of the invention will be set forth in part in the description which follows, and in part will become apparent to those skilled in

the art upon examination of the following, or may be learned by practice of the invention. The objects and advantages of the invention may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

## SUMMARY OF THE INVENTION

According to the present invention, the foregoing and other objects and advantages are attained by an electronic film development method and apparatus by which coherency speckle and other defects are reduced to render commercially viable images. The method and apparatus for reducing noise in electronic film development of a substrate bearing a latent image includes applying a chemical solution to a film substrate to expand the substrate a predetermined amount; allowing the substrate to substantially expand to the predetermined amount; scanning the substrate to generate a first scan of the substrate image; inducing development of the substrate; scanning the substrate after development to generate a second scan; and generating an image with reduced noise from the first and second scan information.

## BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a cross-sectional view of a film layer structure being exposed to light in which the method of this invention can be applied.

Figure 2 is a cross-sectional view illustrating coherency speckle in a film layer structure.

Figure 3A is a cross-sectional view of a film layer undergoing electronic film development before emulsion expansion.

Figure 3B is a cross-sectional view of a film layer undergoing electronic film development after emulsion expansion.

Figure 4 is a graph showing the relationship of emulsion expansion over time upon application of a neutral and alkaline solution.

Figure 5 is a graph representing the relationship of application of developer and emulsion development over time.

## DETAILED DESCRIPTION OF THE INVENTION

The invention will now be described in more detail with reference to the various related figures. In the figures, the invention is presented in connection with conventional color film having at least three different layers. Fig. 1 is a representation of how each of three layers of a film 101, sensitive to red, green and blue respectively, are viewed when exposed to light. When the developing film is viewed from the top during development, the top layer is seen clearly while the lower layers are substantially occluded by the opacity of the top layer. Viewed from the rear during development, the back layer is seen while the other layers are mostly occluded. Finally, when viewed by light transmitted through the film, the fraction of light that does penetrate all three layers is modulated by all three layers, and so contains a view of all three layers. More specifically, as a light source 100 at the front 102 of the film 101 transmits light 104 through the various layers of the film 101, a viewer 105 from the front 102 of the film 101 primarily sees light 106 reflected from the blue sensitive layer 108 with some of the light 110 transmitting through all of the layers to be ultimately viewed by viewer 112 from the back 113 of the film 101. When a light source 114 at the back 113 of the film 101 transmits light 115 through the layers, the viewer 116 sees light 118 reflected from primarily the red sensitive layer 120. The viewer 116 also detects a reflection 122 from the antihalation layer 124 which includes coherency speckle. This coherency speckle becomes image-related noise which the present invention reduces. Because of the additional light 122 reflected by the antihalation layer 124, coherency speckle is worse for the rear reflection image; however, coherency speckle also contaminates the front reflection and transmitted images. Thus, its elimination will improve all three images seen by viewers 105, 112, and 116.

Fig. 2 illustrates the phenomenon of coherency speckle in more detail in the context of the present invention. A typical light source 202 emits two photons along paths 204 and 206. These photons penetrate into a milky diffuser 208, such as a silver halide emulsion, deposited on a substrate 210. Depending on the degree of opacity, photons will penetrate a random distance into the diffuser 208 before they hit a particle and are reflected back. The

photon of light traveling along path 204 is shown striking particle 212 and reemerging along path 214. The photon along path 206 strikes particle 216 and reemerges along path 218. In the illustrated case, both paths 214 and 218 reconverge on a viewer 220.

When the light source 202 is a source of coherent light such as a laser, the photons emitted along paths 204 and 206 are coherent in that they are in phase with one another along the wavefront of the light. Assuming that the two particles 212 and 216 are so close together so as to appear overlapping at a single point when detected by viewer 220, the two photons may interfere with each other at the viewer 220, like ocean waves merging from different angles. In particular, if the total length of the two traversal paths 204-214 and 206-218 differ from each other by an integer multiple of the wavelength of the coherent light emitted by source 202, then the photons will constructively interfere with each other at viewer 220. Thus, their electric vectors will add to produce twice the electric field, and four times the power. If, on the other hand, the path lengths differ by an integer multiple and a half of the light source wavelength, the two photons will interfere destructively, meaning the electric vectors will cancel and produce no light at the viewer 220. The effect of this phenomenon over a film surface area which is large relative to the light source wavelength is that on average two coherent photons will produce twice the average power of a single photon. However, the point detected by viewer 220 corresponding to the image particles 212 and 216 may either appear very bright or completely black depending on the degree of interference in the reflected light. This effect is known as coherent speckle and it introduces noise in current methods of electronic film development.

Reference is now made to Figs. 3A and 3B for a description of a related speckle problem unique to electronic film development. During film processing in general, the dry emulsion layer 308 over the film 300 is subjected to an aqueous bath which causes the emulsion 308 to expand. Referring now to Fig. 3A, a light source 302 emits two photons along paths 304 and 306. The photons penetrate into the dry emulsion 308. The photon traveling along path 304 is seen striking particle 312 located within the emulsion 308 and

reemerging along path 314. Similarly, the photon along path 306 strikes particle 316 in the emulsion 308 and reemerges along path 318. In the illustrated case, both paths 314 and 318 reconverge on a viewer 321. Fig. 3B represents the expanded emulsion 320 after it has been subjected to an aqueous bath. As in Fig. 3A, a light source 302 emits two photons along paths 305 and 307. The photons penetrate the expanded emulsion 320. The photon along path 305 is seen to strike particle 312 and reemerge along path 322, and the photon along path 307 strikes particle 316 and reemerges along path 324. Both paths 322 and 324 reconverge on a viewer 321. Because of the expansion of the emulsion 320, the distance between the photon reflecting particles 312 and 316 has also expanded proportional to the expansion of the emulsion 320. This causes the difference in path length between total path 304-314 of the first proton and the total path 306-318 traveled by the second proton within emulsion 308 to increase to the greater difference between paths 304-322 and 306-324 in the expanded emulsion 320. If the difference in distance between the particles 312 and 316 is only a quarter wavelength (less than one four-thousandths of a millimeter in a typical application using infrared light), then a speckle point can completely change from black to white, or from white to black. Thus, any attempt to remove the speckle effect by differencing an image made with the pre-expanded emulsion 308 from the image made with the expanded emulsion 320 can actually make the speckle effect worse by overlaying two different speckle patterns.

The present invention reduces the amount of coherency speckle detected by electronic film development by scanning a substrate bearing a latent image after the emulsion has expanded to its final thickness but before development has begun, and differencing that scan from the resultant post-development scan.

First, a solution is applied to the emulsion to initiate its full expansion. Fig. 4 depicts the emulsion thickness which may contribute to the speckle effect, and the relationship between application of both a non-alkaline pH solution (for example, a neutral solution with a pH factor of 7.0 or less, e.g., that of water) and an alkaline pH solution (pH above 7.0) to emulsion and emulsion thickness.

Upon application of a neutral pH solution at time 402, the transit time period 403 begins. The transit time represents the time it takes for the aqueous solution to be absorbed by the front layers of the emulsion prior to reaching the rear layer as seen by the back of the film. Once the liquid reaches the rear of the film, expansion of the film begins at time 407. The emulsion will continue to expand until it has reached its terminal thickness 405 at time 408. At time 408, the emulsion is saturated and will no longer expand.

As illustrated by the graph, the emulsion thickness will vary depending on the pH of the applied emulsion-expanding solution. Upon application of an alkaline pH solution at time 402, the expansion of the emulsion begins until it reaches its terminal thickness 406 at time 408. According to the present invention, it is after time 408 when the terminal thickness of the emulsion has been reached, but before development has begun, that the prescan of the substrate is optimum for minimizing or eliminating coherent speckle.

One suitable solution for expanding the emulsion is a developer which contains no developing agent. Staple types of developers include HC-110 manufactured by Eastman Kodak of Rochester, New York diluted to a 1:7 ratio. Alternatively, the emulsion-expanding solution could be an activating agent which enables the developing agent to work by elevating the pH of the solution to alkalinity. Typical alkaline activators dissolved in aqueous carriers include but are not limited to sodium sulfite and sodium carbonate.

In another embodiment of the invention, a developer containing a developing agent is applied to the film emulsion. The developing agent reduces silver halide crystals containing latent image centers. Suitable developing agents include but are not limited to Elon, phenidone, and hydroquinone dissolved in an aqueous carrier and are commonly manufactured by Eastman Kodak, Agfa, and others. In this case, the prescan must be done upon the emulsion reaching its final expansion but before the beginning of substantial development. Fig. 5 represents the time relationship between application of the developer and development of the emulsion. Upon developer application at time 502, there is a specific time period, called the induction time 504, before development of the film begins at inertia point 506. As the induction

time proceeds, the optical density of the emulsion increases. There may be a time during which the emulsion expansion and film development phases overlap. In this embodiment, the prescan is optimally performed before the end of the induction time 504 but after the emulsion has substantially expanded. A prescan taken at this point represents the final coherency speckle pattern devoid of unwanted reduced silver halide grains.

If the solution applied to the emulsion is a developer with a developing agent, development begins immediately after the inertia point of the developing agent is reached. If the solution applied to the emulsion did not contain a developing agent, then there is an arbitrarily long time after the film has expanded during which the scan may be made. Once the developing agent is added to the solution on the film, the induction time 504 begins to run. After development has begun, a plurality of scans are performed at spaced time intervals. These scans are then combined into a single post-development scan as is already known in the electronic film development art. The present invention takes the post-development scan containing image and speckle information and differences it pixel by pixel from the prescan information which contains the speckle pattern without the image. During the differencing procedure, a first image and a second image are received in a computer as pixels. Each pixel has a numerical value representing a characteristic, such as luminance, of the substrate corresponding to that pixel. The corresponding pixel information in the first image and second image are combined to create pixel values which will generate a third image in which the speckle pattern has been decreased or entirely eliminated. The combining function may consist of any of a number of mathematical steps or combination of steps including, but not limited to, dividing and subtracting. As a result of combining the first and second images in the present invention, the speckle pattern will be nulled out or significantly reduced.

In general two-component film development, a non-alkaline solution comprising a developing agent is typically applied first, then an alkaline activator is applied subsequently. However, there are situations in which a better result may be obtained if the order in which the agents are applied is

reversed or if both developer and activator agents are applied in a single solution that comprises both developer agents and activator agents. The combined solution approach is more common in the art of film development.

While this invention has been described with an emphasis upon certain preferred embodiments, variations in the preferred composition and method may be used and the embodiments may be practiced otherwise than as specifically described herein. Accordingly, the invention as defined by the following claims includes all modifications encompassed within the spirit and scope thereof.

## CLAIMS

1. A method for reducing noise in electronic film development of a substrate bearing a latent image comprising:

applying a first solution to said substrate to expand said substrate to a predetermined degree;

allowing said substrate to expand to said predetermined degree;

scanning said expanded substrate to generate a first scan;

inducing development of said substrate;

scanning said substrate after the development inducing step to generate a second scan; and

combining said first scan and said second scan to generate an image with reduced noise.

2. The method of claim 1 wherein said first solution comprises a developing agent and an activating agent.

3. The method of claim 1 wherein said first solution comprises a non-alkaline pH solution.

4. The method of claim 1 wherein said first solution comprises an alkaline solution.

5. The method of claim 1 wherein said first solution comprises an alkaline activating agent.

6. The method of claim 1 wherein said first solution comprises a developing agent.

7. The method of claim 1 wherein said substrate comprises an emulsion containing particles that cause speckle interference.

8. The method of claim 1 wherein said predetermined degree represents a terminal expansion of said substrate.

9. The method of claim 8 wherein said first scan occurs after said terminal expansion is substantially reached but before substantial development of said substrate.

10. The method of claim 2 wherein said first solution causes both emulsion expansion and induction of development.

11. The method of claim 7 wherein the development inducing step comprises applying a second solution to said substrate prior to said second scan.

12. The method of claim 11 wherein the second solution comprises a developing agent.

13. The method of claim 11 wherein the second solution comprises an activator agent.

14. The method of claim 11 wherein said predetermined degree represents a terminal expansion of said substrate and said first scan occurs before the end of an induction time and after said terminal expansion is reached.

15. The method of claim 1 wherein said second scanning step comprises generating a plurality of scans during development.

16. The method of claim 15 further comprising combining said plurality of scans into a single post-development scan.

17. The method of claim 1 wherein said first and second scans read quantitative pixel information representing radiance received from said substrate.

18. The method of claim 17 wherein said combining step comprises differencing said pixel information from said first and second scans.

19. The method of claim 18 wherein said differencing step comprises dividing said pixel information from said second scan by said corresponding pixel information from said first scan.

20. The method of claim 1 wherein said first scanning step occurs before an induction time has ended and after said allowing step.

21. An apparatus for reducing noise in electronic film development of a substrate bearing a latent image comprising:

means for applying a first solution to said substrate and allowing said substrate to expand to a predetermined degree;

means for scanning said substrate to generate a first scan;

means for inducing development of said substrate;

means for scanning said substrate after development induction to generate a second scan; and

means for combining said first scan and said second scan to generate an image with reduced noise.

22. The apparatus of claim 21 wherein said first solution comprises a developing agent and an activating agent.

23. The apparatus of claim 21 wherein said noise arises from speckle interference caused by particles contained within an emulsion deposited on said substrate.

24. The apparatus of claim 21 wherein said predetermined degree represents a terminal expansion of said substrate.

25. The apparatus of claim 21 wherein said first solution comprises a developer.

26. The apparatus of claim 21 wherein a second solution is applied to said substrate to induce development prior to said second scan.

27. The apparatus of claim 26 wherein said second solution comprises a developing agent.

28. The apparatus of claim 26 wherein said second solution comprises an activating agent.

29. The apparatus of claim 21 wherein a plurality of scans are generated during development.

30. The apparatus of claim 21 wherein said first and second scans read quantitative pixel information representing radiance received from said substrate.

31. The apparatus of claim 21 wherein said combining means is a means for differencing said pixel information from said first and second scans.

32. The apparatus of claim 31 wherein said differencing means is a means for mathematically dividing said pixel information from said second scan by said corresponding pixel information from said first scan.

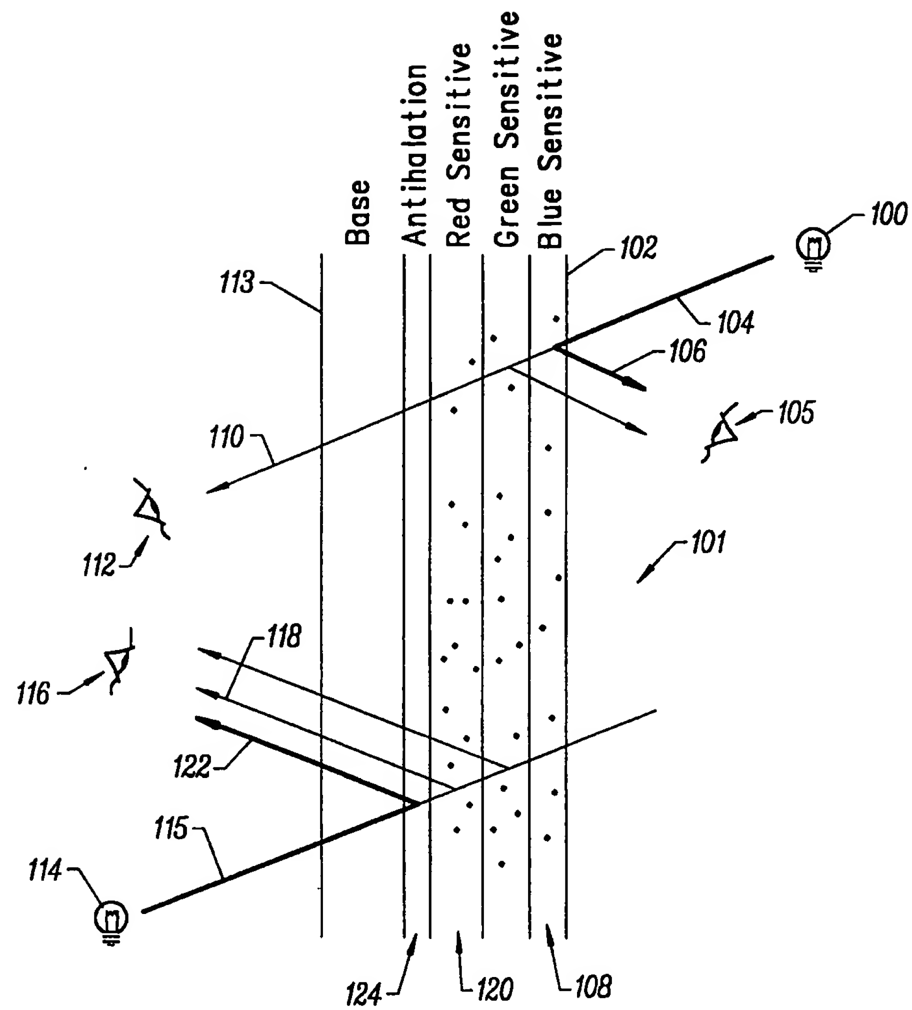
Base
Antihalation
Red Sensitive
Green Sensitive
Blue Sensitive
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*FIG. 1*

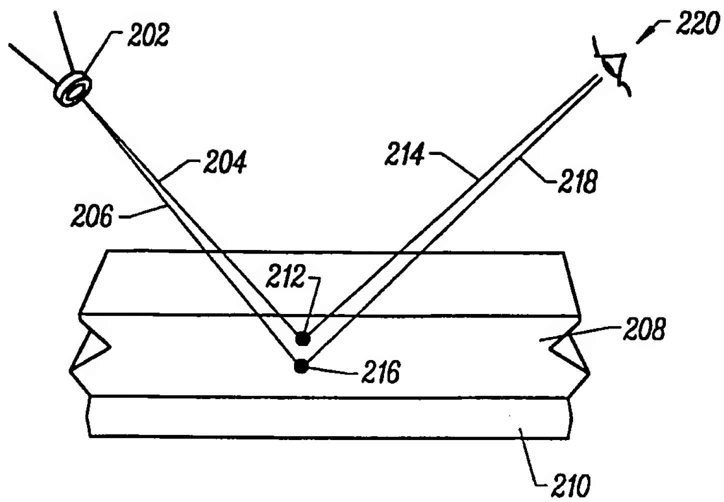


FIG. 2

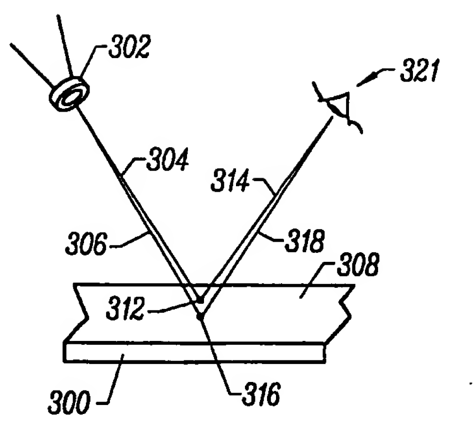


FIG. 3A

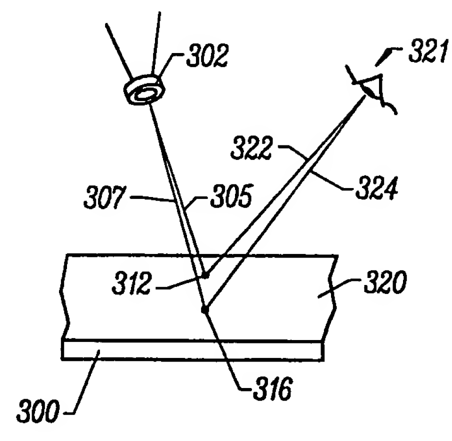


FIG. 3B

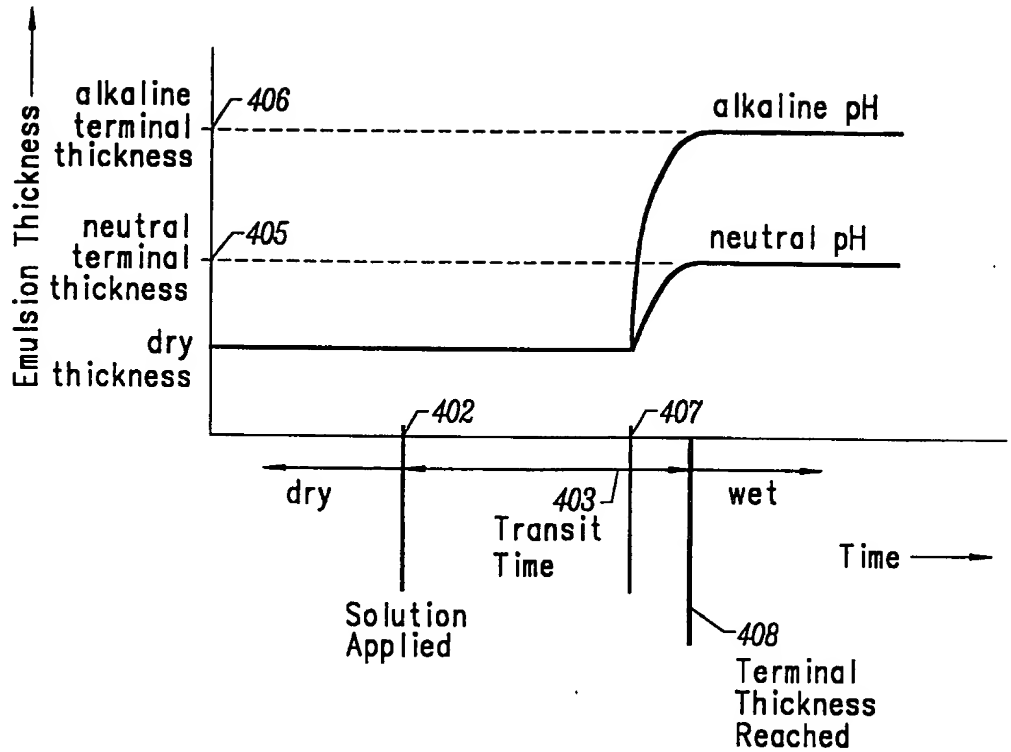
Emulsion Thickness
alkaline terminal thickness
neutral terminal thickness
dry thickness
406
405
alkaline pH
neutral pH
402
407
dry
403
Transit Time
wet
Time
Solution Applied
408
Terminal Thickness Reached

FIG. 4

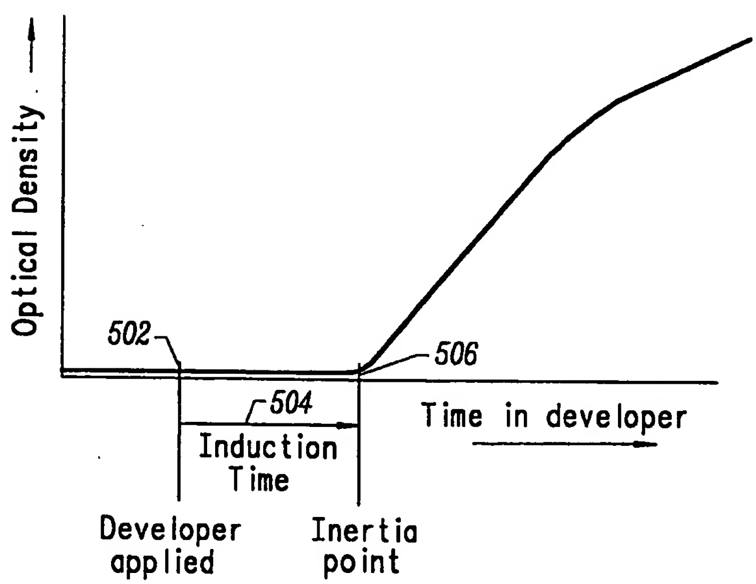
Optical Density
502
506
504
Induction Time
Time in developer
Developer applied
Inertia point

FIG. 5

**INTERNATIONAL SEARCH REPORT**

International application No.
PCT/US97/22849

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(6) :H04N 1/38
US CL :358/463
According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 358/463, 468, 474, 528; 348/96-112

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS
search terms: substrat?(3a)expan?(2p)scan?(3a)(film? or substrat?)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | US 4,957,900 A (YAMAZAKI) 18 September 1990, col. 2, lines 4-39. | 1-32 |
| A | US 5,079,222 A (YAMAZAKI) 07 January 1992, col. 2, line 53 - col. 3, line 29. | 1-32 |

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